SYNCHRONOUS CHANGES IN THE SOLAR AND TERRESTRIAL ATMOSPHERES.

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GENERAL REMARKS.

In my paper, "A contribution to cosmical meteorology," published in the MONTHLY WEATHER REVIEW for July, 1902, evidence was given of the fact that the variation in the solar output, as registered in the relative frequency of the sun spots, has a marked synchronism with the variation of the areas inclosed by the curves representing the horizontal magnetic force of the terrestrial field. This is of course well known from many investigations, but the special features of the paper showed that the sun spots constitute only a sluggish register of the solar activity, and that the terrestrial magnetic force exhibits a set of characteristic minor fluctuations superposed upon the general 11-year curve. These special variations reappear with marked distinctness in the solar prominences as measured by their observed frequency, and also in the variations of the mean annual barometric pressures in all portions of the earth. The significance of this exhibit is its indication that the pressures in the earth's atmosphere are undergoing changes in short cycles of about three years average duration, which correspond with the changes in the external work of the sun. A further study of our meteorological records during the past few month convinces me that these short cycles are produced by modifications in the general circulation of the earth's atmosphere, which produce alternate accelerations or retardations of general movements, and that these raise or lower the average annual barometric pressure over large districts of the earth's surface. There is also a sort of surging of the atmosphere with more or less stationary configurations or structures, and these involve the so-called seasonal climatic changes of weather by which one year differs from another. Thus, the regions about the Indian Ocean and South America vary synchronously but inversely; the continental and the ocean areas appear to change in an inverse manner; there seems to be a tendency to generate a great cyclic change having a period of about eight years within which the pressure excesses begin, for example in India, pass through Asia, Europe, North America, and South America back to India. This synchronism between the solar and terrestrial variations is found in the United States to hold for the pressures, temperatures, the storm-track movements in latitude and longitude, the cold-wave tracks, and generally for all the elements of the atmosphere. I have elsewhere sufficiently described my views regarding the causes of this synchronism, and it must be evident to all that meteorology has a great interest in elucidating these fundamental problems of solar physics, since our hope of making seasonal forecasts of the weather will be fulfilled only by reducing our knowledge of the complex connections between the sun and the earth to a scientific basis. I can at this time present the result of only one portion of my work in this direction, with an indication of the nature of the problems that must be solved by astrophysicists in order to perfect our knowledge of terrestrial meteorology.

DISTRIBUTION IN LONGITUDE.

It is desirable to study the distribution of the effects of the solar activity at the surface of the sun in both longitude and latitude, and their variations in the 11-year period. Passing over the subject of the true period of the sun's rotation, which is now being discussed by scientists, and which would require a longer statement than is here possible, it may be noted that whatever period is adopted for an ephemeris, the frequency numbers for spots, faculæ, and prominences collected in tables will show a drift to the right or left according as the period

is too short or too long. For example, if in constructing an ephemeris one adopts as the mean period of rotation that which is proper to the sun spots at latitude $\varphi = 12°$, which is 25.23 (siderial) days with the diurnal angle 14.27°, as Spörer and Wolfer have done, and collects together the faculæ in longitude, it is found that charts of successive rotations of the sun on this ephemeris show a trend to the right for the years 1887–1889, but a trend to the left in the years 1890–1892. This is due to the fact that just preceding the minimum of the solar-spot and faculæ period, these formations occur chiefly in low latitudes, within 5° to 10° of the solar equator, but after the minimum in latitudes 20° to 25°. In the former set the rotational period is much shorter than in the latter, that preceding minimum being shorter, and that following minimum being longer, than the period at 12° latitude. Thus Wolfer finds the diurnal angle of rotation 14.41° (or rotational period 24.98 days) in latitude 5°, but 13.92° (with period 25.86 days) in latitude 22°, as against 14.27° (with period 25.23 days) in latititude 12°.[1]

Wolfer's charts show a distinct trend to the right for the spots, faculæ, and prominences during the years 1887–1889, but to the left for the years 1890–1892. In the case of the prominences, which occur in all latitudes of the sun, we may expect to have an opportunity to discuss the surface rotation in higher latitudes than those of the spots and faculæ, since these are confined to the zones ± 30°. I am engaged in such compilation of the data of the prominences observed in Italy from 1871 to 1900, but am not able to make any further statement at present. It is evident that whatever fundamental rotation period may be selected it can be corrected by the tabular drift as just indicated. There is to be noted, however, an important feature of the distribution in longitude as given on Wolfer's charts, namely, that the recurrence of the spots and faculæ does not happen at random in all degrees of longitude, that is on all solar meridians, but they are arranged in two well defined group systems, which repeat themselves during many rotations, and these are located approximately on the extremities of a single diameter, that is, they occur on meridians about 180° apart. There seems to be a solar meridian plane on which the output is constitutionally more vigorous, or as Wolfer indicates the fact, the sun has centers of activity on opposite sides of its mass. This peculiar distribution along the equatorial belt would seem to imply that
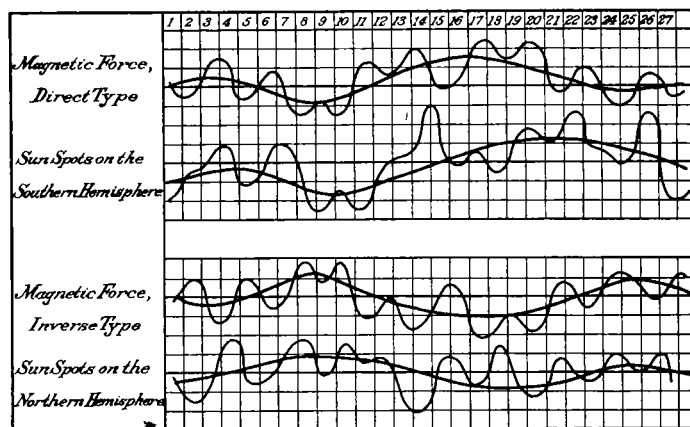
FIG. 1.—Comparison of the total sun-spot areas, 1854–1891, with the magnetic curves in the 26.68-day period.

the mass of the sun tends to erupt more freely on opposite sides of the center along one of its diameters, and this may lead to some knowledge or inference as to its physical interior condition. It may be a viscous mass somewhat elliptical in

[1] Publikationen der Sternwarte des Eidg. Polytechnikums zu Zurich. A. Wolfer. Bd. I, II, III. 1897, 1899, 1902.

FIG. 2.—Observed variation of the relative frequency of the solar prominences in 10-degree zones.

shape, or at least affording freer egress for the escaping products of compression along one axis. This phenomenon is best seen at times of minimum activity, because near the maximum the output so far increases in vigor as to be distributed more equally in all longitudes, and to conceal this special tendency to concentrate along a given axis.
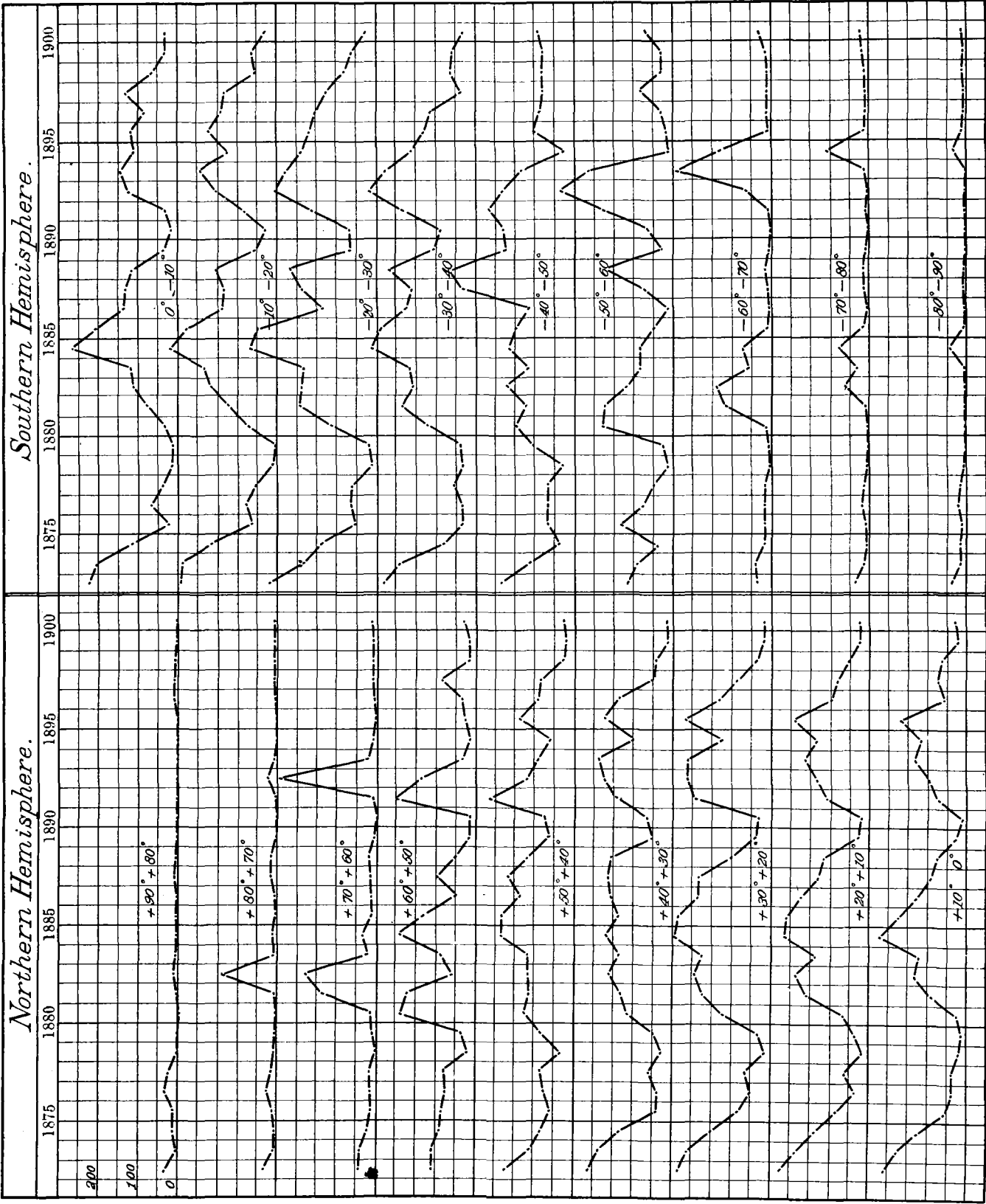
An entirely similar result was obtained in my discussion of the solar spots by taking an ephemeris based upon the period of the rotation at the equator, that is, 26.68 days (synodic). Compare Bulletin No. 21, Solar and Terrestrial Magnetism, Weather Bureau, 1898, page 141, or Bulletin I, Eclipse Meteorology, page, 91. The compilation of the deflecting vectors of the terrestrial magnetic force gives a curve of the same type as do the primary and secondary variations.

An inspection of the groups of spot numbers in the tables in which the data were collected does not indicate any tendency to drift to the right or left as one passes through the great 11-year cycles, and this shows that the spots have sufficiently short lives relatively to this period to be subordinate to the primary source of the output from the solar nucleus, which latter must have some properties independent of the observed surface phenomena themselves. The angular velocity of surface drift varies in latitude, but the internal action that produces spots appears to be united closely with the observed period at the equator itself, and there is also reason to believe that the period at the equator is the same as that at the poles. The equatorial plane may be assumed to rotate with the same velocity as the interior mass and to have the true period of rotation. The observations indicate that there is a structure which produces an excess of output on certain meridians about 180° apart. This is the result of our discussion of the distribution of the solar activity in longitude, and we will now proceed to consider the evidence that there is a structural distribution of energy in latitude.

DISTRIBUTION IN LATITUDE.

The Italian observations of the solar prominences made by Secchi, Tacchini, and Ricco, from the year 1871 up to the present time, published in the Memorie della Società degli Spettroscopisti Italiani, constitute a valuable series of data as homogeneous in character as it is possible to produce. A shorter series by Rev. J. Fenyi, S. J., at the Haynald Observatory, Kalocsa, has been published for the years 1884 to 1890, inclusive, and additional volumes of this important work are in preparation. Sir Norman Lockyer has recently published in volume 70 of the Proceedings of the Royal Society some conclusions derived from the Italian data, but I have for myself collected together the frequency numbers for the sake of their bearing upon the problem of the circulation of the mass of the sun which is about to be described. Lockyer's curve and my own agree in showing the same variation of the annual frequency numbers for the years 1871 to 1900, inclusive. My compilation has been extended to include the solar spots and faculæ for the interval 1880 to 1900. For the years 1872–1877, Secchi collected his data by periods of solar rotation, using the period 27.78 days; for the years 1878–1900 Tacchini and Ricco have collected the data by the calendar months. I have reduced the Secchi series to the year intervals, in order to make the annual numbers homogeneous with the Tacchini series. The number of observations of the prominences, spots, and faculæ has been distributed into 10-degree zones in latitude from the north pole to the south pole of the sun for each rotation and month, respectively, of the two series, that is, 90° to 80°, 80° to 70°, ... —70° to —80°, —80° to —90°. The sums are taken by zones, and also by rotations or months, and are checked by producing the same annual sum. The annual numbers of prominences, spots, and faculæ, respectively, were plotted on diagrams in order to exhibit the changes going on in the sun during the three past 11-year cycles, but these

charts and the expanded tables are not reproduced in this present paper.

It was concluded, as the result of a careful examination of the charts, that the average variation of the output could be most satisfactorily reduced to a law by combining these three cycles together, and thus eliminating to some extent two sources of irregularity, (1) that due to the spasmodic action of the sun, and (2) that caused by the difference of cloudiness from season to season in Italy, which modified the number of days available for the observations. The numbers are collected in groups of three years each, beginning 1872, 1883, 1894, as shown in Tables 1 and 2. The years which correspond with each other in the 11-year cycle are placed together, and it makes no difference where the mean cycle begins to be numbered. By passing down the table from 1872, three times in succession, the annual numbers are found, and can be used in other discussions. The data are now exhibited in several ways. On fig. 2 is given the variations found by plotting the annual numbers in each 10-degree zone in succession for the years 1872–1901. Thus, in the 90° to 80° zone of the northern hemisphere we have from Table 1 the numbers 35, 3, 9, 10, ... which give the first broken line of the chart. Viewing this chart as a whole we make the following notes: (1) The 11-year cycle variation is strongly developed in the equatorial zones and diminishes in intensity toward the polar zones, where it has nearly disappeared. (2) By plotting the mean annual numbers only the prominence variation line is produced; see the first curve of fig. 28, in my article No. VII, "A contribution to cosmical meteorology," published in the MONTHLY WEATHER REVIEW for July, 1902. (3) Although there is considerable variation in the amplitude of the same annual frequency number, that is, in the series of crests formed during the same year in different zones, it is evident that the sun is affected throughout its photosphere by the increase and decrease of the output of energy as registered in the prominence numbers. (4) The irregularity, however, is so large as to show that the sun acts like a congested and discharging viscous mass, through a series of distortions, accelerations, and retardations, in different parts of its mass, and that it does not transfer its internal energy into outside work uniformly and symmetrically. It is extremely important to remember this because in discussing the data for the period of the solar rotation, *we do not have a series of independent events to combine*, as the theory of least squares or the law of errors demands. It is preferable to work out the period by methods more practical than the application of the Fourier series and the Schuster periodogram, which depend upon the occurrence of independent events, and an expectancy based upon the law of errors. The sun does not exhibit a steady potential system of either electric or magnetic forces, nor any steady recurrence of events upon its surface which can be combined by rigid analytic laws. This is a natural consequence of the fact that the mass of the sun fills an immense volume in space and is experiencing congestion and escape of heat energy generated by gravitational compression. It is, furthermore, necessary to free the solar data from terrestrial meteorological effects before any type of least square analysis can be properly applied. To emphasize this point more fully, Tables 3, 4, and 5, derived from the original tabulation, give the sums for each rotation or month, respectively, for the entire solar surface, by summing up the numbers found in the several zones. It is seen that in the monthly means of the prominences there is a very distinct annual variation in the number of prominences observed. This can be due only to the annual change in the Italian climatic conditions which affected the making of the observations, and it shows that the recorded frequency numbers are not free from a strong terrestrial term which must modify all discussions in solar physics, unless satisfactorily eliminated. The tables for the solar faculæ show the same seasonal variation as the prominences, but less con-

TABLE 1.—*Mean observed distribution in latitude during the 11-year solar cycle. Solar prominences.*

Years.	90°/80	80°/70	70°/60	60°/50	50°/40	40°/30	30°/20	20°/10	10°/0	0°/-10	-10°/-20	-20°/-30	-30°/-40	-40°/-50	-50°/-60	-60°/-70	-70°/-80	-80°/-90	Annual sums.
(1)																			
1872	35	39	47	106	164	218	229	225	207	216	246	270	234	184	120	33	34	38	2,645
1883	9	10	22	97	116	141	172	138	125	121	187	193	169	112	88	56	32	8	1,796
1894	2	1	9	15	58	99	125	136	116	111	123	196	161	30	14	130	106	35	1,467
Mean	15	17	26	73	113	153	175	166	149	149	185	220	188	109	74	73	57	27	1,969
(2)																			
1873	3	10	38	107	107	181	206	165	175	201	235	182	188	106	92	40	7	10	2,053
1884	3	11	42	195	191	165	245	213	217	263	266	322	265	164	91	72	83	48	2,856
1895	0	1	4	29	131	169	212	194	166	124	171	167	135	101	20	3	7	6	1,640
Mean	2	7	28	110	143	172	221	191	186	196	224	224	196	124	68	38	32	21	2,183
(3)																			
1874	9	5	24	94	84	130	150	141	125	116	161	138	82	93	44	10	2	7	1,415
1885	3	3	17	139	181	139	229	208	175	201	232	299	242	148	48	6	12	2	2,284
1896	6	3	4	37	93	141	131	100	53	89	147	151	117	92	28	9	7	3	1,211
Mean	6	4	15	90	119	137	170	150	118	135	180	196	147	111	40	8	7	4	1,637
(4)																			
1875	10	13	15	87	60	46	78	81	55	26	61	52	44	61	137	19	5	6	856
1886	1	9	18	48	132	152	180	172	130	141	146	139	174	116	16	4	5	2	1,585
1897	4	6	8	90	81	52	91	85	74	138	139	126	41	76	80	11	6	5	1,113
Mean	5	9	10	75	91	83	116	113	86	102	115	106	86	84	78	11	5	4	1,185
(5)																			
1876	40	29	19	76	75	39	50	43	41	66	84	65	44	66	77	19	20	23	876
1887	12	15	15	99	162	161	178	136	96	134	140	192	156	287	70	9	12	3	1,877
1898	5	9	12	17	26	47	39	52	59	62	102	89	61	79	29	13	11	9	721
Mean	19	18	15	64	88	82	89	77	65	87	109	115	87	144	59	14	14	12	1,158
(6)																			
1877	25	18	17	33	78	53	62	57	39	43	52	60	54	64	50	13	13	11	742
1888	8	16	25	49	117	152	99	116	75	110	155	216	220	317	176	16	15	5	1,887
1899	5	10	11	16	23	13	17	24	24	31	56	57	54	82	31	17	21	6	498
Mean	13	15	18	33	73	73	59	66	46	61	88	111	109	154	86	15	16	7	1,042
(7)																			
1878	1	7	3	19	34	34	13	16	17	12	9	8	35	31	8	1	3	1	252
1889	2	2	6	21	62	51	36	32	30	38	52	65	104	174	39	6	4	0	724
1900	5	9	16	36	30	18	19	25	27	35	31	32	31	96	68	31	24	10	543
Mean	3	6	8	25	42	34	23	24	25	28	31	35	57	100	38	13	10	4	506
(8)																			
1879	1	5	13	46	85	49	33	29	10	9	4	24	45	101	27	5	3	1	490
1890	3	1	0	19	75	66	29	22	11	15	30	69	96	185	61	1	0	2	685
Mean	2	3	7	33	80	58	31	26	11	12	17	47	71	143	44	3	2		588
(9)																			
1880	0	4	21	187	128	110	121	63	26	37	70	110	119	148	177	14	2	1	1,338
1891	3	5	16	199	215	146	182	107	69	34	91	160	183	220	178	17	7	4	1,836
Mean	2	5	19	193	172	128	152	85	48	36	81	135	151	184	178	16	5	3	1,587
(10)																			
1881	5	13	143	169	107	132	175	153	93	76	126	197	191	116	170	115	15	2	1,998
1892	0	23	247	137	119	172	207	136	98	124	154	252	272	183	283	62	2	1	2,472
Mean	3	18	195	153	113	152	191	145	96	100	140	225	232	150	227	89	9	2	2,235
(11)																			
1882	21	146	177	56	108	160	196	193	133	114	168	198	157	172	118	141	63	6	2,327
1893	0	10	25	29	93	187	206	158	132	149	195	229	226	138	208	242	13	1	2,241
Mean	11	128	101	43	101	174	201	176	133	132	182	214	192	155	163	192	38	4	2,284

spicuously developed, while the sun-spot means are practically unaffected by the climatic changes. This difference must be attributed to the relative length or duration of the three phenomena, the spots having a life sufficiently long to bridge over the gaps covered by cloudy weather in Italy, so that the true number of spots which occur on the sun is really counted. This is true of the faculæ to a lesser degree because their lives are shorter than the sun spots, and some come and go in the intervals of stormy weather without being enumerated at all. The prominence numbers especially are subject to loss by not being observed continuously, because their life is usually very brief, so that the prominences which occur in successive meridian areas and are seen only on the edge of the sun can not be fully counted under ordinary observing conditions. The Kalocsa observations exhibit similar disturbances due to the conditions. If the observations of 1884–1890 be collected in a similar manner to that adopted above, we find that the numbers increase decidedly from 1884, which is a maximum year, to 1890 which is a minimum year, and this is contrary to the probable course of the events. The Italian observations decrease from 1884 to 1890, and the two series are opposite to each other in this respect, though they give similar zonal distributions so far as the maxima are concerned. Steadiness in observing and elimination of cloudy weather was therefore indispensable in order to procure reliable data for these discussions in solar physics. So far from being independent almost all solar data are mutually dependent upon adjacent events, and Professor Schuster's method of the periodogram is subject to this sort of limita-
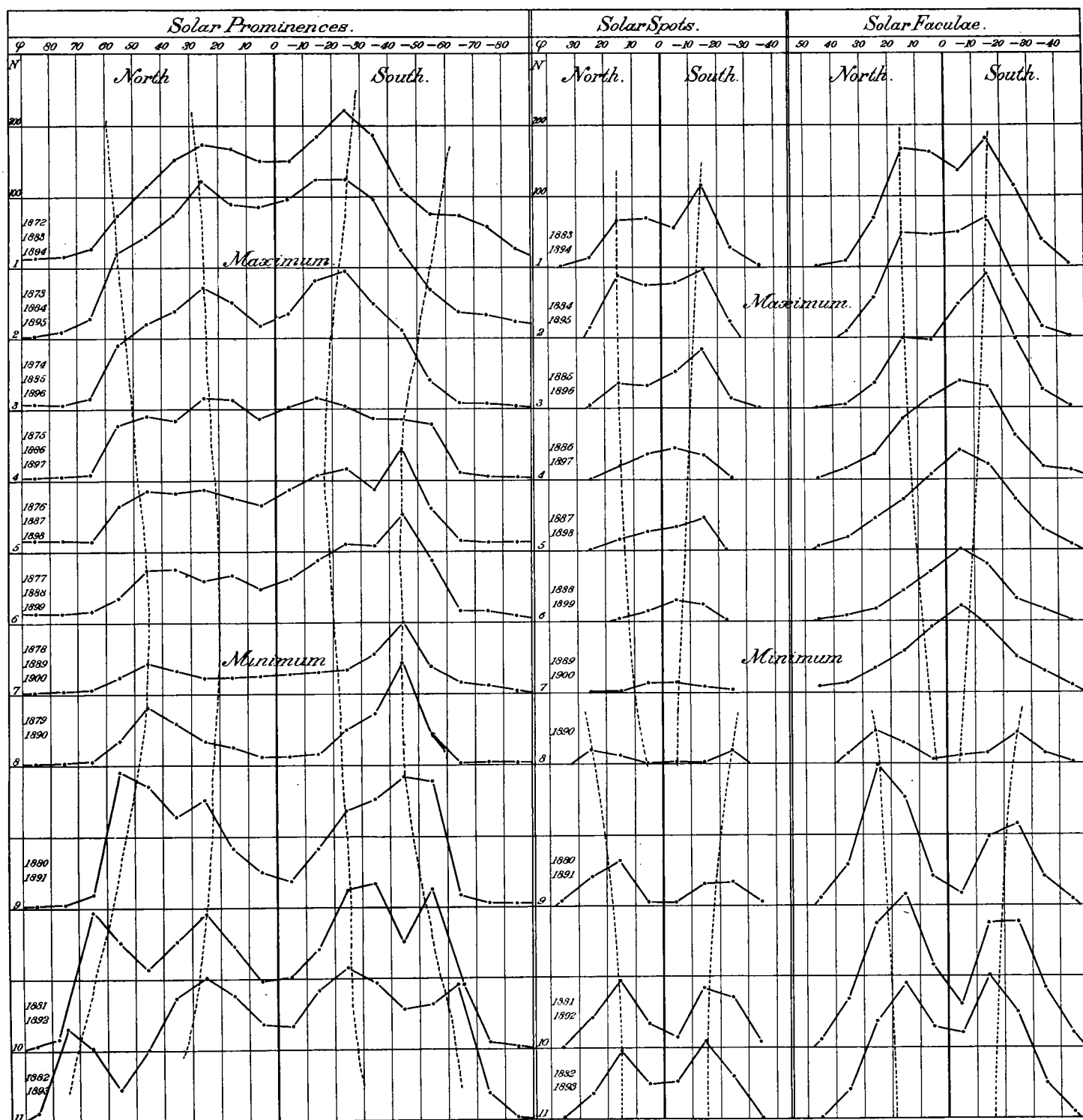
FIG. 3.—Mean variation of the distribution in latitude during the 11-year periods of the interval 1872–1900.

TABLE 2.—*Mean observed distribution in latitude during the 11-year solar cycle. Solar spots and faculæ.*

Years.	SOLAR SPOTS.									SOLAR FACULÆ.										
	40°/30	30°/20	20°/10	10°/0	0°/-10	-10°/-20	-20°/-30	-30°/-40	Annual sums.	Above 40°	40°/30	30°/20	20°/10	10°/0	0°/10	-10°/-20	-20°/-30	-30°/-40	Below -40°	Annual sums.
(1) 1883	1	7	57	63	58	107	20		313		7	68	175	154	117	159	89	24		793
1894	1	21	71	73	56	129	33	3	387	1	6	64	152	166	154	199	139	53	7	941
Mean	1	14	64	68	57	118	27	2	350	1	7	66	164	160	136	179	114	39	4	867
(2) 1884		11	92	85	109	113	22		432		4	44	135	143	174	168	69	11		748
1895		19	85	61	44	82	24		315		9	69	161	145	121	167	104	14	1	791
Mean		15	89	73	77	98	23		374		7	57	148	144	148	168	87	13	1	770
(3) 1885		3	32	38	75	80	6	2	236	1	2	20	97	99	164	169	40	2		594
1896		2	41	28	29	89	19		208		7	55	100	96	129	209	156	45	5	802
Mean		3	37	33	52	85	13	1	222	1	5	38	99	98	147	189	98	24	3	698
(4) 1886		1	21	17	32	25	2		98		4	8	39	47	70	63	23	3	1	258
1897			17	52	58	42	2		171	3	25	62	129	181	207	197	96	27	19	946
Mean		1	19	35	45	34	2		135	2	15	35	84	114	139	130	60	15	10	602
(5) 1887		1	10	10	30	20			71	1	5	9	21	32	53	39	7	1	1	169
1898			23	45	38	74			180	6	32	76	122	181	226	200	133	53	15	1,044
Mean		1	17	28	34	47			126	4	19	43	72	107	140	120	70	27	8	607
(6) 1888			3	14	35	10			62		1	2	9	37	71	38	2			160
1899			6	15	25	40			86	8	15	36	75	103	130	118	62	33	2	582
Mean			5	15	30	25			74	4	8	19	42	70	101	78	32	17	1	371
(7) 1889		3	0	5	15	3	8		34	1	2	6	6	15	30	19	12	2	1	94
1900			4	21	18	14			57	15	28	65	112	171	211	168	90	57	20	937
Mean		2	2	13	17	9	4		46	8	15	36	59	93	121	94	51	30	11	516
(8) 1890		20	13	1	3	3	21		61		15	45	31	6	11	16	44	14	1	183
(9) 1880	6	24	45	8	7	33	32	3	158	19	85	244	150	45	21	124	146	60	14	908
1891		57	85	6	1	27	33	6	215	1	33	152	155	37	12	71	83	19	1	554
Mean	6	41	65	7	4	30	33	5	187	10	59	198	153	41	17	98	115	40	8	731
(10) 1881		52	93	22	12	79	61		319	15	109	253	279	121	58	195	187	92	32	1,341
1892	2	34	93	44	16	89	78	12	368	4	27	100	156	112	61	152	167	72	11	862
Mean	1	43	93	33	14	84	70	6	344	10	68	177	218	117	60	174	177	82	22	1,102
(11) 1882		35	80	38	37	68	40		298	3	50	161	188	107	85	163	120	37	9	923
1893	1	39	115	55	67	148	79	6	510	3	29	110	189	148	154	238	173	57	6	1,107
Mean	1	37	98	47	52	108	60	3	404	3	40	136	189	128	120	201	147	47	8	1,015

tion. The same is true of almost all the terrestrial meteorological elements, and generally a negative result which is derived from the discussion of a periodic or cyclic curve is valuable only when it is certain that the data conform to the analytic presuppositions, such as are laid down in the theory of the energy curve. Schuster applied his theory to the Greenwich magnetic declinations taken from day to day, where the hourly variation is eliminated. It can be shown that the declination is a component which vanishes in theory, and exists in practise only as a measure of the feeble variations of the earth's field which are distinctly accidental and only remotely connected with the solar action.

VARIATIONS IN LATITUDE IN THE 11-YEAR CYCLE.

We will now consider the prominences, spots, and faculæ in the 11-year cycle in order to discover whether there is some evidence of a periodic variation in the latitude at which the output from the interior of the solar mass becomes visible to us. An inspection of the details of the three cycles contained within the interval of time 1872–1900, shows that there is a triple repetition of similar variations in these elements, and suggests that the mean values of the years similarly placed in the 11-year period may be taken as a close approach to the law underlying these cyclical changes. The means of Tables 1 and 2 are plotted on fig. 3. The scale denotes the frequency numbers as counted from the Italian observations, and the zones are indicated by the degrees at the top of the chart. Dotted lines are drawn through the systems of the maximum numbers to mark the difference in latitude at which these develop. The prominences have two distinct maxima, generally, throughout the period, except that the one in high latitudes, 60°–70°, nearly disappears at the time of maximum spot frequency and the one in low latitudes, 20°–30°, practically disappears at the time of the minimum number of spots. After the minimum which has crests in high latitudes there is a vigorous recrudescence of the prominences in two distinct belts of maxima, 20°–30° and 40°–50°, with a tendency to diverge toward lower and higher latitudes; the higher varies 25° in latitude and the lower less than 10°. This swing in latitude of the maximum points is accompanied by a decided

TABLE 3.—*Italian observations.   Observed mean monthly distribution of the solar prominences.*

Rotation.	1872.	1873.	1874.	1875.	1876.	1877.	Mean.
1	202	150	91	37	13	40	89
2	229	200	135	69	51	75	127
3	214	130	140	60	51	59	109
4	157	188	93	55	26	37	93
5	219	180	97	65	51	55	111
6	229	139	107	45	42	95	110
7	281	215	96	48	47	54	124
8	315	229	105	124	107	115	166
9	287	105	111	131	114	82	138
10	143	190	163	51	105	42	116
11	129	89	75	71	83	31	80
12	130	98	115	46	88	54	89
13	110	140	35	54	59	3	67
14	......	......	52	......	39	......	......

Month.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.
January	3	7	13	45	229	95	139	104	116	115	198	76
February	26	4	71	80	242	137	186	197	98	134	107	84
March	39	7	145	88	184	97	317	146	126	137	197	140
April	33	......	54	109	146	133	212	111	82	129	266	49
May	31	12	81	210	183	183	237	226	162	127	181	19
June	27	64	146	177	269	122	237	351	174	257	117	20
July	59	57	260	299	288	219	364	328	233	268	154	62
August	22	61	137	284	249	167	399	221	162	231	222	99
September	......	80	137	187	169	133	233	177	149	161	144	75
October	4	100	120	121	137	233	269	104	68	69	158	29
November	8	58	77	258	139	135	152	126	138	141	73	47
December	......	40	97	140	92	142	111	193	77	108	70	24

Month.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.
January	25	60	83	145	87	28	134	60	53	45	40	83
February	27	170	95	214	141	69	155	69	42	38	13	104
March	29	110	122	272	159	127	71	109	31	40	20	118
April	38	138	158	324	104	131	77	85	60	45	32	109
May	31	98	207	143	114	141	103	84	26	18	48	116
June	63	108	330	161	178	181	125	119	77	51	36	147
July	60	256	323	167	157	257	143	81	64	52	68	183
August	82	210	296	267	167	246	105	113	78	44	56	170
September	68	220	305	185	116	178	106	143	121	76	96	142
October	175	217	186	138	78	93	102	101	86	42	60	117
November	36	98	216	70	104	114	55	95	27	28	20	96
December	51	151	151	155	62	75	35	54	56	19	54	85

TABLE 4.—*Observed mean monthly distribution of the solar spots.*

Month.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.
January	15	20	28	29	56	26	8	6	7	......	3
February	5	19	27	19	32	37	9	7	5	4	1
March	9	19	32	14	43	16	18	6	4	4	2
April	6	38	27	32	35	19	14	5	8	1	6
May	9	34	24	23	37	23	8	8	2	1	6
June	10	25	16	26	28	28	11	8	3	1	4
July	13	54	27	22	42	18	9	11	5	7	4
August	18	14	17	29	44	20	5	3	10	4	6
September	24	22	22	22	37	13	8	6	10	2	13
October	24	25	30	35	32	15	2	4	1	3	8
November	14	26	28	28	23	14	1	2	4	......	3
December	11	23	20	34	23	7	5	5	3	7	5

TABLE 4.—*Observed mean monthly distribution of the solar spots*—Continued.

Month.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	Means.
January	8	34	33	36	36	19	19	12	12	5	20
February	11	21	23	27	19	20	11	18	7	5	16
March	9	25	36	34	26	25	19	14	6	4	17
April	18	29	60	24	36	20	22	14	11	10	21
May	17	29	41	37	22	16	11	12	2	7	18
June	21	36	39	35	29	13	4	21	7	6	18
July	29	33	49	38	24	21	15	11	9	6	21
August	20	28	66	38	28	11	10	10	2	2	18
September	23	29	49	41	30	23	23	13	6	7	20
October	22	44	49	19	24	16	19	29	11	3	20
November	17	25	32	34	15	11	5	17	5	2	15
December	20	35	33	24	26	13	13	9	8	......	15

TABLE 5.—*Observed mean monthly distribution of the solar faculæ.*

Month.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.
January	34	52	64	60	81	57	18	12	17	1	21
February	53	59	81	54	73	82	16	16	7	1	12
March	109	87	92	45	74	64	30	20	17	4	13
April	29	123	76	57	61	42	25	9	14	4	7
May	47	150	80	61	50	58	40	15	8	6	15
June	57	128	79	56	67	63	40	24	12	7	12
July	74	181	116	39	68	41	32	15	14	12	14
August	81	141	80	58	64	46	13	14	18	24	17
September	136	161	64	92	66	56	18	9	24	12	27
October	115	102	50	101	47	22	9	7	8	11	12
November	86	85	62	86	50	31	5	12	9	2	16
December	87	72	79	84	47	32	12	16	12	10	17

Month.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	Means.
January	8	52	68	79	54	56	63	83	34	73	47
February	37	42	76	76	38	61	60	67	70	45	49
March	30	56	87	53	70	68	65	78	31	71	55
April	43	71	91	57	88	89	83	62	39	76	55
May	52	75	119	68	49	75	69	132	48	52	60
June	63	97	107	103	87	62	89	94	56	95	67
July	75	94	125	88	90	83	91	132	83	68	73
August	64	59	94	86	68	82	116	138	98	146	72
September	46	84	85	86	66	68	68	97	12	97	65
October	51	92	78	74	60	66	72	57	14	76	54
November	37	65	65	96	75	40	95	45	51	38	50
December	48	75	112	75	46	52	75	59	46	100	55

variation in the number observed, as indicated by the change in the areas included between the lines of prominence numbers and the axis of abscissas. The spots and the faculæ have each only one maximum in the same hemisphere, which gradually approaches the equator from about latitude 25° at the time of recrudescence just following the maximum number. The dying spots of an old cycle in low latitudes very near the equator occur while a new series of spots is appearing in the higher latitudes. Fig. 3 tells its story so clearly that it is not necessary to describe it in greater detail.

We can bring out its meaning, however, in connection with the probable internal circulation from the interior of the sun more distinctly by constructing the movement of the maximum point of relative frequency in latitude during an 11-year cycle of the solar prominences, spots, and faculæ, see fig. 4. The point on fig. 3 where the dotted maximum line crosses the line of relative frequency fixes the latitude of the maximum number. Hence, we take for coordinates the number from the scale of ordinates and the latitude from the abscissas (*N*, φ) and transfer these coordinates in succession from year to year to fig. 4. The first point in the prominence curve in the northern solar hemisphere is for the year 1894 (*N* = 64, φ = 57°), and this is plotted at latitude 57° at the same scale

distance from the solar disk, as on fig. 3 from the axis of abscissas, and marked 94, meaning the year 1894. The successive points mark the locus of the movement of this maximum in the 11-year cycle. The same method is applied to the two prominence systems of maxima in each hemisphere, and to the single maximum of spots and faculæ in each hemisphere, respectively, the latter being plotted on the left-hand side of fig. 4 in order not to confuse the drawing. The diagram is to be interpreted as representing the variations of the maximum solar output in belts or zones extending around the entire photosphere.

It is instructive to note the regular course that this variation pursues, and this is of fundamental importance as indicating some characteristic conditions of the solar circulation. Beginning with the minimum years 1889 and 1890, the polar group of prominences rises rapidly until 1891, turns quickly toward the pole until 1893, then diminishes the number and gradually completes the circuit, with slow decrease of latitude, to 1899. The southern polar group maximum traces quite the same circuit, which has a considerable area and a peculiar lip at the years of minimum frequency. The equatorial prominence group begins in latitude 22°, rises quickly to a maximum height in the same latitude, lingers nearly in the same position

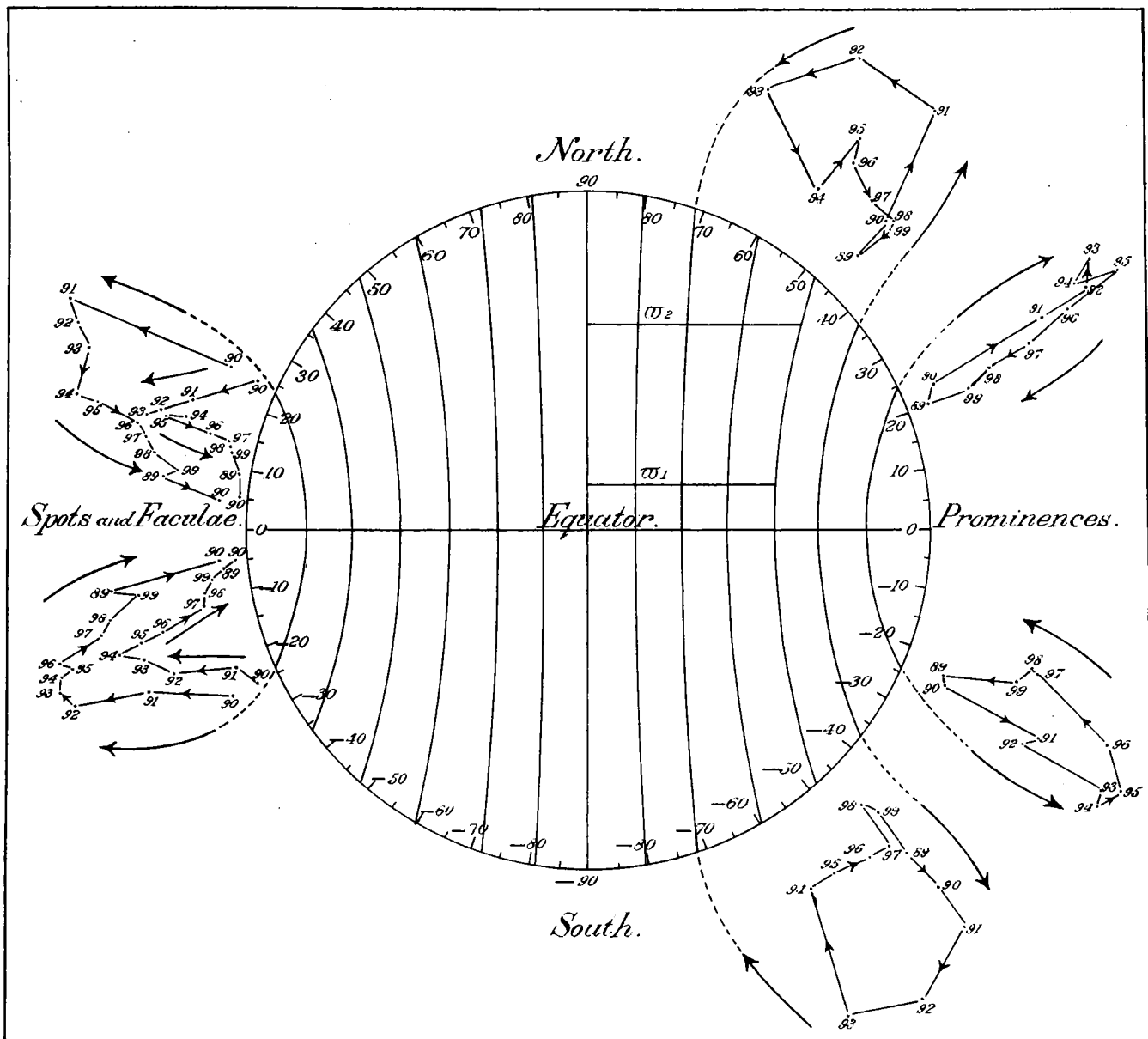FIG. 4.—Movement of the maximum point of relative frequency in latitude during an 11-year cycle of the solar prominences, spots, and faculæ.

for several years (1893–1895), with small decrease in latitude, and is followed by a gradual return to the beginning of the circuit. The same remarks hold true for both hemispheres. The equatorial area is long and narrow and the polar approximately equilateral in form, showing that the former changes less in latitude than the latter, the height being about the same in each case. I have drawn some large arrows to show that a general movement outward is indicated for latitudes 22° to 45° at the recrudescence of the prominences, and that there is a movement inward in the equatorial and in the polar latitudes.

A similar construction for the faculæ shows that after the minimum they also spring up powerfully to their greatest frequency in latitude 25°, and that they decline gradually with diminution of the latitude till they reach a minimum, where the characteristic double-belt occurrence takes effect. The spots construct a triangular area, well within that covered by the faculæ, and they increase more slowly and decline more regularly than do the faculæ, while the latitude is diminishing. The heavy arrows drawn on fig. 4 indicate an outward impulse in the middle solar latitudes and an inward movement nearer the equator. This result is in perfect harmony

with that obtained for the prominences, and we can not avoid the conclusion that the sun in cooling emits energy and discharges material more vigorously in the middle latitudes than in the polar and the equatorial regions. This suggests the primary conditions of the circulation which prevail for a large mass like the sun cooling by discharge of matter and by radiation.

Care should be taken not to misinterpret the long arrows which have been placed upon fig. 4. These represent the direction of the rising of the maximum points to their highest positions and then the sinking back toward the surface. As shown by fig. 3 the entire solar surface is emitting outward, even when the arrow is pointing inward. Nevertheless, the movements of the maximum points in latitude and altitude must be attributed to an excessive output of energy, and this points to a fundamental circulation of the heat energy and of the material substances in the sun. The next problem in solar physics is to discover the laws that control this special variation of the distribution of energy.

It is proper in this connection to reproduce the lines of the Helmholtz–Emden thermal structure, already noted in Bulletin I, Eclipse Meteorology and Allied Problems, p. 71. The in-

3——3

terior curves computed from Helmholtz's equations harmonize so happily with the exterior lines derived from this discussion on the output of the sun, that the probability is strengthened that this scheme is the proper one with which to enter upon the analysis of the internal circulation of the sun. As already noted in that bulletin, if the vortex law ($\omega\varpi^2 =$ constant, where $\varpi =$ the radius and $\omega =$ the angular velocity) holds good in this case, then we have an explanation of the cause of retardation of the diurnal angular velocity of the motions of the photosphere in middle latitudes as referred to the equatorial or polar belts. For if $\varpi_2 > \varpi_1$ then $\omega_2 < \omega_1$, and since ω_1 is the initial rotational velocity at the equator, the angular velocity in middle latitudes must be less than at the equator or at the poles. This agrees with the result of the surface observations. Furthermore, the equatorial angular velocity is probably that of the interior mass, or nucleus of the sun, and the poles should have the same velocity, a result in harmony with that deduced from my discussion of the terrestrial magnetic field. This equatorial and polar angular velocity gives a 26.68-day synodic period for the rotation of the sun. Finally, the middle latitudes must give a slower angular velocity and a greater period, such as 27.30 days in the belts 12° to 15°. Since the mass of the sun ought not by this theorem to have in any portion of it an angular velocity less than that of the equatorial plane, it does not appear to be reasonable that the short periods of about 25.80 to 26.00 days, which several investigators have announced as that of the sun's rotation derived from a discussion of several different terrestrial phenomena, can be correct. It is very difficult to perceive how there can be any basis for a period shorter than 26.68 days; on the contrary these authors seem to find a period at least one day shorter than the quickest period that can be derived from the observations and discussions of surface solar phenomena. It is very probable that the problem of the circulation within the sun must be worked out before we can hope to bring that of the rotation of the solar mass to a satisfactory understanding.

CLIMATOLOGY OF COSTA RICA.

Communicated by H. PITTIER, Director, Physical Geographic Institute.
[For tables see the last page of this REVIEW preceding the charts.]

Notes on the weather.—On the Pacific slope the weather was about normal, but for a slight excess of heat and the extreme dryness of the atmosphere, as can be seen from the observations at San José. On the Atlantic slope rain was generally scarce.

Notes on earthquakes.—January 1, 0^h 45^m a. m., protracted shaking E–W, intensity IV, duration 28 seconds. January 2, 1^h 49^m a. m., tremors. January 3, 5^h 32^m a. m., slight shock E–W, intensity II, duration 5 seconds. January 3, 10^h 39^m p. m., tremors. January 13, 8^h 12^m 46^s p. m., strong shock N–S, intensity III, duration 3 seconds.

HIGH WINDS IN MOUNTAIN VALLEYS.

By ALTON D. ELMER, Northfield, Mass., dated February 10, 1903.

I inclose a newspaper clipping relative to the storm of January 31, 1903, which may interest you, as it is illustrative of a phenomenon which is a part of every extra high wind from west or northwest in the Green Mountain passes. The pressure on the west side of the Appalachians seems to break through the cuts like water, with disastrous results to the towns in the valleys facing them. The towns at the mouths of the passes (Readsboro and Wilmington, Vt., being examples) of course suffer the most. I only send you one cutting, relating to a sample valley town, not in the mouth of a pass.

HIGH WIND AT ZOAR, MASS.

W. D. Rifenburg, who has charge of the wrecking crew, is authority for the following story: He says that when the west bound freight, 205, was passing through Zoar, Saturday, the wind struck an empty box car with tremendous force and lifted it bodily from the trucks and tipped it over on the east bound track. The portion of the car was jacked up, and again the wind struck and tipped it over. When the wreck was cleared the men waited in the station, when the wind struck it with such force that the men thought the station would blow down and left it. All the men say they never encountered such a terrific wind in their lives.

Reports from all such valley towns would fill a scrapbook. This phenomenon should not be compared with that of the easterly winds (see MONTHLY WEATHER REVIEW, 1897, Vol. XXV, pp. 212, 307; 1898, Vol. XXVI, p. 66), inasmuch as the east and southeast gales seem to attain their destructive force in the valleys at the leeward bases of mountain ranges.

CLIMATOLOGICAL DATA FOR JAMAICA.

Through the kindness of H. H. Cousins, chemist to the government of Jamaica and now in charge of the meteorological service of that island, we have received the following table in advance of the regular monthly weather report for Jamaica:

Comparative table of rainfall for January, 1903.

Divisions.	Relative area.	Number of stations.	Rainfall. Average.	Rainfall. 1903.
	Per cent.		*Inches.*	*Inches.*
Northeastern division	25	21	5.38	3.00
Northern division	22	47	3.38	1.99
West-central division	26	21	2.19	1.73
Southern division	27	32	1.70	1.03
	100	121	3.16	1.94

The rainfall for January was therefore much below the average for the whole island. The greatest rainfall, 8.82 inches, occurred at Port Antonio, in the northeastern division, while at Fort Hill in the southern division 0.05 of an inch fell.

Comparative table of rainfall for December, 1902.

Divisions.	Relative area.	Number of stations.	Rainfall. Average.	Rainfall. 1902.
	Per cent.		*Inches.*	*Inches.*
Northeastern division	25	21	9.91	14.82
Northern division	22	47	5.72	11.60
West-central division	26	21	3.78	4.07
Southern division	27	32	2.66	2.45
	100	121	5.52	8.23

The rainfall for the whole island was, therefore, considerably above the average. The heaviest fall recorded was, 47.94 inches, at Moore Town, in the northeastern division, while 0.32 of an inch fell at New Yarmouth in the southern division.

THE SOUTHERN LIMIT OF A NORTHWEST GALE.

By H. H. TENBROECK, of Braidentown, Fla.

On the morning of September 9, 1902, there was an instance of the meeting and arresting of a northwest gale in the neighborhood of Braidentown, Fla.

At sunrise there was a bank of very dark clouds in the northwest that rose slowly and showed the rolling overhanging mass that characterizes such clouds. The wind was fresh from the southeast, the sky was generally covered with very threatening, dense cumulus clouds. By 8 a. m. the bank in the northwest had risen about 15° or 20° with every indication of a squall of wind and rain immediately. But the bank began to grow lighter, the overhanging rolling mass disappeared and the whole broke up into a mass of ill-defined cumulus clouds, the wind increasing in force from the southeast and the clouds becoming more dense and threatening. By noon, however, the wind lessened in force, the clouds became thinner and more scattered, and the bank in the northwest entirely disappeared. Twice before I have noted the same phenomenon of a northwest gale reaching its limit.

Thinking that a note of this occurrence might add a grain of information about the very interesting matter of air currents, I send it to you.